Geo-Electric Evaluation Of Aquifer Protective Capacity And Groundwater Flow Pattern In Ogbia Local Government Of Bayelsa State, Nigeria

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***Abstract*—The groundwater flow pattern and aquifer protective capacity of overburden layers in some communities of Ogbia in Bayelsa State was investigated to determine the vulnerability of groundwater resources due to infiltration and/or migration of potential contaminants. These communities plays host to crude oil exploitation activities, as such, environmental degradation associated with these activities are commonplace. Spills, leachate plumes from dumpsite and waste from septic tanks may contaminate the aquifers indiscriminately. Dar Zarrouk parameters obtained from the geoelectric sounding was used to evaluate the protective capacity of the soil, while the groundwater flow pattern was determined by contouring the hydraulic heads obtained from elevation and static water level measurements in wells across the study area.12 vertical electrical soundings (VES) using the Schlumberger electrode configuration were occupied in the study area, longitudinal conductance values delineated areas with poor (less than 0.1 mho), weak (0.1 – 0.19 mho), moderate (0.2 – 0.69 mho) and good protective capacity (0.7 – 1.0 mho). The geoelectric results suggest that sections of the aquifer underlying Otuasega and Imiringi communities have the least protective capacity indices and thus were most vulnerable to contamination due to infiltration and percolation. This study has shown that groundwater flow is generally from the northern part to the southern regions in the study area; hence communities in the south are more likely to be adversely affected by contaminants transport within the aquifer system.**

Keywords—Groundwater, triangulation, aquifer vulnerability, flow direction, hydraulic head.

INTRODUCTION

Groundwater is a complex, generally dilute, chemical solution. The chemical composition is derived mainly from the dissolution of minerals in the soil and the rocks with which it is or has been in contact. The direction of groundwater flow follows a curved path through an aquifer from areas of high water levels to areas where water levels are low; that is from below high ground, which are recharge areas, to groundwater discharge points in valleys or the sea. The direction of flow is indicated by the slope of the water table which is called the hydraulic gradient [5].When groundwater is pumped from a borehole, the water level is lowered in the surrounding area. A hydraulic gradient is created in the aquifer which allows water to flow towards the borehole. The difference between the original water level and the pumping level is the drawdown, which is equivalent to the head of water necessary to produce a flow through the aquifer to the borehole. The surface of the pumping level is in the form of an inverted cone and is referred to as a cone of depression. Water flows into a borehole from all directions in response to pumping and as it is flowing through a decreasing cylindrical area, the velocity increases as it converges towards the borehole [4]. By knowing the direction of groundwater flow, communities can map out the land area that recharges their public supply wells and thereby take steps to ensure that land use activities in the recharge area will not pose a threat to the quality of groundwater and the resources dependent on it. Since contaminants generally move in the direction of groundwater flow, communities can also predict how contaminants might move through the local groundwater system [12].

The study area comprises a number of communities in Ogbia Local Government Area of Bayelsa State; from Otuasega at the northern end through Ogbia to Emakalakala in the south. These communities play host to a number of oil flow stations and pipeline tie-points, as such, oil spillages from ruptured pipelines which adversely affect the ecosystem and possibly the groundwater are common place. Additionally, consequent upon urbanization is the increase in waste generation; hence, a common feature in the area is that refuse dumps are ubiquitous. Besides oil spills and poor refuse management, the uncontrolled location and leakage of domestic and industrial septic tanks are potent sources that can contaminate the underlying aquifers. Considering these environmental challenges, there is dire need to have a picture of the subsurface protective capacity of the aquifers and establish the groundwater flow pattern in the study area.

Geophysical methods comprise of cost effective, rapid, non-invasive techniques that can be used to investigate the protective capacity of aquifers. Reference [6] showed that the combination of layer resistivity and thickness in the Dar Zarrouk parameters (longitudinal conductance) and (transverse resistance) may be of direct use in aquifer protection studies, and for the evaluation of hydrologic properties of aquifers because the protective capacity of a clayey aquifer overburden is proportional to its longitudinal unit conductance. The protective capacity is therefore considered to be proportional to the longitudinal unit conductance [8],[1].

PHYSIOGRAPHY AND GEOLOGY OF STUDY AREA

The study area is located within longitude 6.3400^0 E and 6.3900^0 E and latitude 4.6000^0 N and 4.9000^0 N of the equator (Fig. 1) with an average elevation of about 15m above mean sea level. It lies within the saltwater and freshwater swamp geomorphic units of the Niger Delta Sedimentary Basin of Southern Nigeria which is characterized by nearly flat topography sloping very slightly seawards [3]. The swamps are vegetated tidal flats formed by a reticulate pattern of interconnected meandering creeks and tributaries of the River Niger. The Niger Delta is located in the humid climatic region of the rain forest with characteristic seasonal and torrential down pours. It is influenced by both the Southwest Monsoon and North East Harmattan winds, although the former's influence spans over two-thirds of the year. Rainfall in the coastal belt of the Niger Delta is heavy due to the closeness of the delta region to the equator. Annual rainfall totals vary from 2400 mm landwards to over 4800 mm at the coast [9].

The geologic sequence of the Niger Delta consists of three main tertiary subsurface lithostratigraphic units which are overlain by various types of quaternary deposits [10]. The base of the unit is the AkataFormation; it is comprised mainly of marine shales with some sand beds. The formation ranges in thickness from about 550 m to over 6,000 m. Very little hydrocarbon has been associated with the formation. The Agbada Formation is the overlying paralic sequence which consists of interbedded sands and shale with a thickness of 300 m to about 4,500 m, thinning both seawards and towards the Delta margin. The topmost unit is the Benin Formation; it is comprised of over 90 % sandstone with shale intercalations. It is coarse grained, gravely, locally fine grained, poorly sorted, sub angular to well-rounded and bears lignite streaks and wood fragments [2]. The unit is thickest in the central area of the delta. The contact with the underlying Agbada formation is defined by the base of sandstones which also corresponds to the base of the fresh water bearing strata.

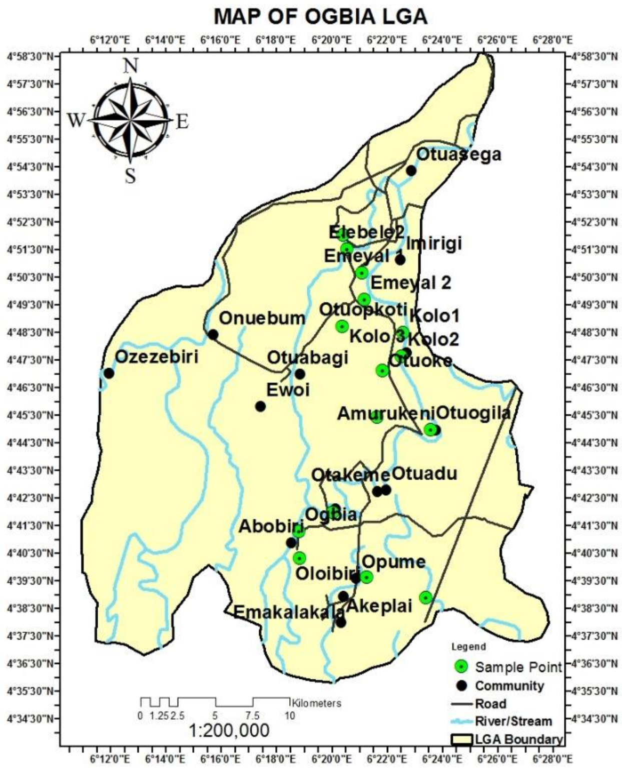

Fig 1: Map of Ogbia showing the study area

METHODOLOGY

Two distinct but hydrogeologically related field data sets were obtained in the course of this study. Firstly, parameters necessary for the determination of the groundwater flow direction was acquired and secondly Vertical Electrical Sounding (VES) for the evaluation of the protective capacity of aquifers.

Determination of Hydraulic Head

The Garmin Global Positioning System (GPS) which is satellite based equipment for position determination was used to record the longitude, latitude and surface elevations with respect to the mean sea level at selected borehole locations distributed within the study area. A coaxial water level meter was used to measure the static water level in the wells. At each station, the well pump was turned off for at least two hours before measuring the water level to ensure that conditions are static (non-pumping) in the well. The coaxial water level meter is an electric device that uses a thin, round wire to transmit a signal to a buzzer when water is encountered. This type of meter is useful in wells where access to the borehole is narrow or if a pump is installed. Hydraulic head which is the elevation to which water will naturally rise in a well was obtained by subtracting the depth to the static water level from the ground elevation with respect to the mean sea level.

Resistivity Survey (VES)

Vertical Electrical Sounding investigation using the Schlumberger electrode configuration with a maximum current electrode spread (AB = 800 m) was employed in this research. Twelve (12) vertical electrical soundings (VES) were carried out in close proximity to the borehole locations. The Abem Terrameter SAS 1000, a self-averaging digital device was used for the field operation. The field procedure was carried out by applying current to the ground through two electrodes (A and B) and then measuring the resultant potential difference (ΔV) between the potential electrodes (M and N). The centre point of the electrode array remained fixed but the spacing of the electrodes was systematically increased so as to obtain information about the depth and stratification of the ground. The VES data were interpreted and layer parameters such as true resistivities and thicknesses were obtained. The geoelectric parameters were used to generate the Dar Zarrouk parameters from which the aquifer protective capacity was subsequently evaluated.

RESULTS

Groundwater Flow

The parameters for the determination of groundwater flow direction are presented in Table1. Graphical contouring of the field measurements based on triangular linear interpolation was first used to determine local groundwater flow for various sections of the study area to serve as a control for subsequent computer modeling and is diagrammatically illustrated in Fig. 2 [11]. The results from the application of the three point solution shows that flow is towards well 3 (Otuoke), well 2 (Emakalakala) and well 3 (Otakeme) as illustrated in Fig 2a, 2b and 2c respectively. Only certain sections of the study area were covered by the graphical approach. Computer generated contour map is essential in groundwater studies because it is desirable to have the integrated final map as an XYZ computer file. Fig. 3 is the computer generated map of the study area showing various trends in the flow direction using SURFER 11.

Table 1: Parameters for Determination of Groundwater Flow Direction

S/No	Location	Longitude (^{0}E)	Latitude (^{0}N)	Elevation (m)	SWL (m)	Hydraulic Head (m)
1	Elebele1	6.3400	4.8671	20.3	5.1	15.2
2	Elebele2	6.3426	4.8586	19.5	4.6	15.9
3	Emeyal1	6.3517	4.8444	18.2	2.1	16.1
4	Emeyal2	6.3531	4.8283	19.6	1.8	17.8
5	Otuopkoti	6.3395	4.8121	18.0	2.5	15.5
6	Kolo1	6.3762	4.8080	19.3	2.5	16.8
7	Kolo2	6.3752	4.7938	21.7	2.7	19.0
8	Otuoke	6.3640	4.7852	14.5	2.2	12.3
9	Otuogila	6.3928	4.7497	15.0	2.0	13.0
10	Otakeme	6.3606	4.7572	19.0	1.8	17.2
11	Ogbia	6.3137	4.6885	14.2	1.3	12.9
12	Otuogidi	6.3342	4.6997	13.6	2.1	11.5
13	Opume	6.3543	4.6608	12.1	1.5	10.6
14	Oloibiri	6.3644	4.5281	13.1	2.1	11.0
15	Emakalakala	6.3902	4.6481	11.8	2.1	9.7

Geo-electric Investigation

Twelve (12) VES stations were occupied using various current electrode separations ranging from AB =180 m to 400 m. The choice of the spread length was constrained either due to thick vegetation, compact nature of buildings and other cultural impediments in the investigation sites. The VES curves were interpreted quantitatively by computer iteration using the IP2WIN software to obtain the first-order geoelectric parameters (the layer resistivityρ_i and the layer thickness h_i) for the i^{th} layer (i = 1 for the surface layer) and presented in Table 2. Analysis of the geoelectric layers showed that the first layer also known as the top soil had resistivity of 95 Ωm – 213Ω m, with thickness of 0.5 m – 1.1 m. Underlying the top soil is the second layer with significant decrease in resistivity values ranging from 22 Ωm – 103 Ωm and thickness ranging from 3.9 m – 6.2 m. The composition of this layer is clayey sand – silty sand – fine sand. The 3rd layer resistivity values range from 165 Ωm in station 5 to 522 Ωm in station 8 with thickness ranging from 32.8 m – 52.4 m, occurring at an average depth 6.8 m. The 4th layer have resistivity values ranging from23Ωm in station 11 to 387 Ωm in station 9 located an average depth of 39.4 m with thickness ranging from 8.1 m – 36 m.The third and fourth layers are generally aquiferous and composed of medium to coarse sand. However, for the locations exhibiting five-layers, 2 aquiferous zones were also delineated (the 3rd and 5th layers) but separated by a clayey layer with average thickness of about 11.3 m and resistivity of 23 Ωm – 97 Ωm which tends to create local semi-confined conditions. The fifth layer has thickness and resistivity values of 35.0 m – 57.8 m and 322 Ωm – 1021 Ωm respectively and is aquiferous. Fig. 4 is a geoelectric section which proximally cuts across 10 of the sounding stations in an approximately north-south trend.

Table 2: Geoelectric results and longitudinal conductance values

VES No.	Location	Thickness of layers (m)					Resistivity of layers (Ωm)						∑ LC (mhos)	Protective Capacity
		h_1	h_2	h_3	h_4	h_5	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	ρ_6		
1	Otuasega	0.7	3.9	35.2	12.7	46.5	172	68	314	46	830	1347	0.01638	Poor
2	Oruma	0.6	4.1	44.6	12.3	54.2	105	47	293	34	1021	2836	0.244	Moderate
3	Elebele	0.5	5.7	41	36		103	66	190	318	124		0.605	Moderate
4	Imiringi	0.6	4.0	42.9	8.1	36.5	126	50	485	62	518	974	0.1	Weak
5	Emeyal	0.8	4.2	51.5	10.7	55.4	98	31	165	40	621	2120	0.722	Good
6	Kolo	0.9	4.3	32.8	13.5	57.8	112	65	183	27	363	1245	0.8675	Good
7	Otuoke	0.7	4.5	39.2	9.8	43.5	104	79	265	31	449	1689	0.44	Moderate
8	Ogbia	1.1	4.2	52.4			176	81	610	232			0.052	Moderate
9	Otuogidi	0.7	6.2	37	29		95	22	206	387	57		0.467	Moderate
10	Oloibiri	0.5	4.0	49.1			213	97	513	179			0.044	Moderate
11	Opume	0.8	3.9	51.8	11.0	56.5	182	103	285	23	540	901	0.708	Good
12	Emekalakala	0.7	4.2	44.6	10.2	35	113	58	263	97	322	784	0.415	Moderate

The first-order geoelectric parameters were utilized in deriving the longitudinal unit conductance (Lc), otherwise known as the Dar Zarrouk parameter [7].

$$\mathrm{Lc} = \sum_{i=1}^{n} \frac{\mathrm{hi}}{\rho\mathrm{i}} \quad (1)$$

The overburden protective capacity was evaluated by utilizing the total longitudinal unit conductance values of Eq. 1 [6]. Table 2 also shows the calculated longitudinal conductance values from the geoelectric measurements in the study area.

The protective capacity was interpreted based on the [6] longitudinal conductance/protective capacity rating in Table 3.

Table 3: Protective capacity rating (after Henriet, 1976)

Sum of longitudinal unit conductance (mhos)	Overburden protective capacity classification
< 0.1	Poor
0.1-0.19	Weak
0.2-0.69	Moderate
0.7-1.0	Good

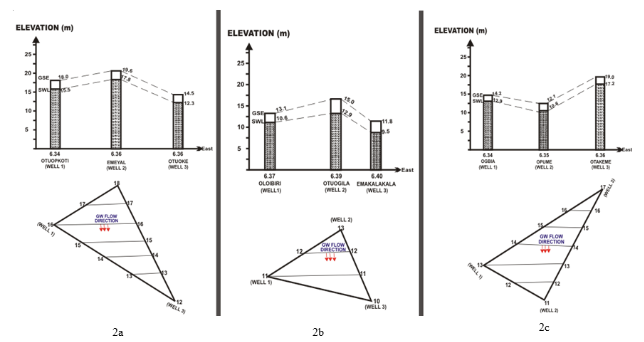

Fig. 2: Graphical determination of groundwater flow direction in selected sections of study

DISCUSSION OF RESULTS

The results obtained from the computer aided contouring of the aquifer system within the study area shows that the overall groundwater flow is dominantly from the northern zone through the central regions to the south. The results also suggests that inordinate land use activities such as indiscriminate solid waste disposal, underground leakage of sewage and petroleum storage facilities in the region would be more detrimental for communities situated within the southern zones of the study area.

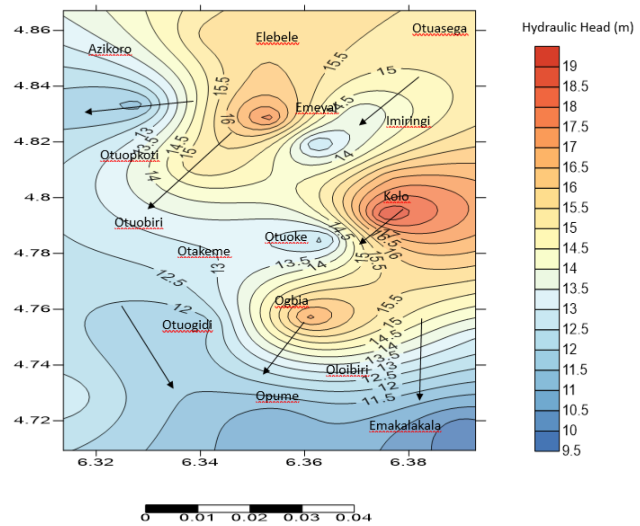

Figure 3: Contour map of study area showing groundwater flow direction

The implication of this with respect to aquifer vulnerability is that boreholes sited in the southern area are more susceptible to receive transported contaminants from the northern part of the study area. It is thus advisable to site municipal boreholes in the north while location of landfills and active solid waste dumpsites should be restricted to the southern sections of the study area.

The protective capacity evaluation/rating based on the determination of the longitudinal conductance and the interpreted geoelectric profile shows that sections of the aquifer at OtuasegaandImiringi fall within the poor and weak categories respectively. Oruma, Elebele, Otuoke, Ogbia, Otuogidi and Oloibiri are designated moderate, while aquifer sections underlying Emeyal, Kolo and Opume are rated as having good protective capacity.

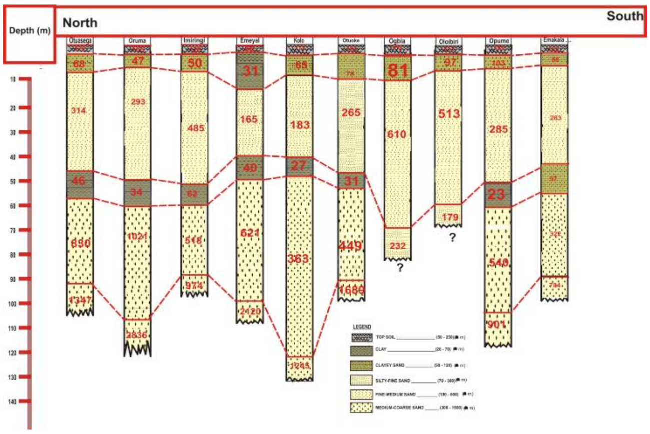

Fig. 4: Geoelectric section across VES stations

CONCLUSION

This study has shown that groundwater flow is generally from the northern part to the southern regions in the study area; hence communities in the south are more likely to be adversely affected by contaminants transport within the aquifer system. Furthermore, the geoelectric studies also suggests that sections of the aquifer underlying Otuasega and Imiringi communities have the least protective capacity indices and thus most vulnerable to contamination due to infiltration and percolation. Finally, **t**he behaviour of subsurface water does not necessarily reflect that of the surface, therefore knowledge of subsurface water behaviour becomes an important puzzle that requires a great deal of devotion, skill and research to fully understand. This knowledge enables government, corporate organization and individuals to adequately develop the various water resources available to them, particularly groundwater. Stakeholders in the region should ensure that eco-friendly and sustainable land use practices are encouraged while environmentally harmful practices are minimized so as to avoid contamination of the groundwater resources available within the study area. In addition, pipelines accommodating and transporting petroleum products should be frequently monitored for corrosion and in the event of spillage, remediation measures should be carried out immediately.

ACKNOWLEDGEMENT

The authors are grateful to Elixir Company Nig. Ltd for coordinating the logistics and measurement of static water levels across the study area.

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